Section 1

Measurement—A Common Language

Reading Preview

Key Concepts

- Why do scientists use a standard measurement system?
- What are the SI units of measure for length, mass, volume, density, time, and temperature?
- How are conversion factors useful?

Key Terms

- metric system • SI • mass
- weight • volume • meniscus
- density

Target Reading Skill

Comparing and Contrasting
As you read, compare and contrast different types of measurement by completing a table like the one below.

Measurement

Characteristic	Length	Mass
Definition		
SI unit		
Measuring tool		

Lab zone **Discover Activity**

How Many Shoes?

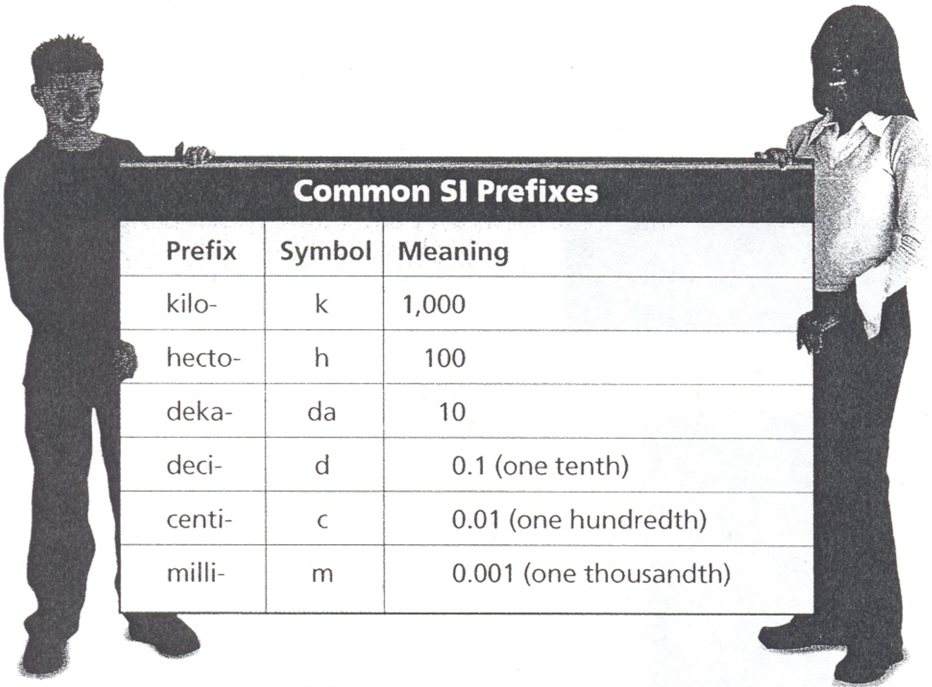
1. Trace an outline of your shoe onto a piece of paper. Cut out your pattern.
2. Use your pattern to measure the length of your classroom in "shoes."
3. Compare your measurement to those of three classmates. Did you all measure the same number of "shoes"?

Think It Over
Inferring Why do you think it is important that people use standard units of measurement?

Did you ever ask a relative for an old family recipe? If so, the answer might have been, "Use just the right amount of flour and water. Add a spoonful of oil and a pinch of salt. Bake it for awhile until it looks just right."

Instructions like these would be difficult to follow. How much flour is "just the right amount"? How big is a spoonful or a pinch? It would be impossible for you to know what your relative had in mind. You could end up with disastrous results.

In tasks such as cooking, measurements can be critical! ▶



Common SI Prefixes

Prefix	Symbol	Meaning
kilo-	k	1,000
hecto-	h	100
deka-	da	10
deci-	d	0.1 (one tenth)
centi-	c	0.01 (one hundredth)
milli-	m	0.001 (one thousandth)

FIGURE 1
SI units, based on multiples of 10, are easy to use. Knowing what the prefixes mean can help you judge how big or small a measurement is.
Calculating *How much larger is a* kilo- *than a* deka-*?*

A Standard Measurement System

The recipe example illustrates the importance of using a standard system of measurement. This is especially true in science. Using the same system of measurement minimizes confusion among scientists all over the world.

The Metric System More than 200 years ago, most countries used their own measurement systems. Sometimes two or more different systems were used in the same country. In the 1790s, scientists in France developed a universal system of measurement called the metric system. The **metric system** is a system of measurement based on the number 10.

The International System of Units (SI) Modern scientists use a version of the metric system called the International System of Units, abbreviated as **SI** (for the French, *Système International d'Unités)*. Scientists all over the world use SI units to measure length, volume, mass, density, temperature, and time. **Using SI as the standard system of measurement allows scientists to compare data and communicate with each other about their results.** In this book and others in the *Science Explorer* program, you will use both SI and other metric units.

Figure 1 lists the prefixes used to name the most common SI units. Because they are based on multiples of 10, SI units are easy to use. Each unit is ten times larger than the next smallest unit and one tenth the size of the next largest unit. This is similar to our money system, in which a dime is worth ten times more than a penny, but one tenth as much as a dollar.

Reading Checkpoint SI units are based on multiples of what number?

Discovery Channel School
The Work of Scientists
Video Preview
▶ Video Field Trip
Video Assessment

Common Conversions for Length		
1 km	=	1,000 m
1 m	=	100 cm
1 m	=	1,000 mm
1 cm	=	10 mm

Length

How far can you throw a softball? Can you judge by eye how far the ball travels? A better way to find out would be to measure the distance, or length, that the ball travels. Length is the distance from one point to another. In the case of your softball throw, it would be from the point where you release the ball to the point where it first hits the ground.

Units of Length **The basic unit of length in the SI system is the meter (m).** One meter is about the distance from the floor to a doorknob. A softball throw would be measured in meters. So would your height. Most students your age are between 1.5 and 2 meters tall.

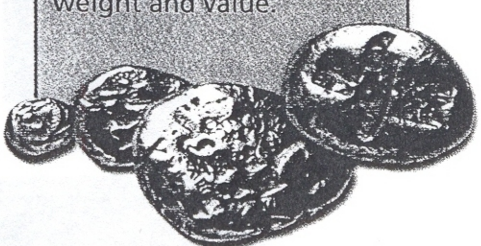
Science and **History**

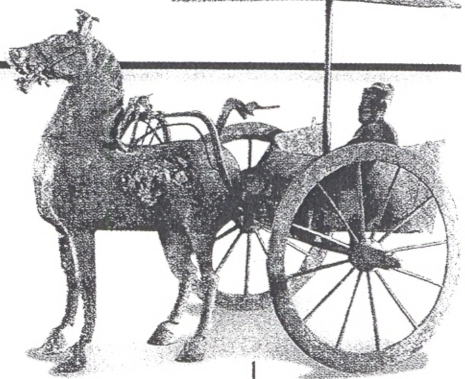
Measurement Systems

Like so much else in science, systems of measurement developed gradually over time in different parts of the world.

1400 B.C.
A Simple Balance
The ancient Egyptians developed the first known weighing instrument, a simple balance with a pointer. Earlier, they had been the first to standardize a measure of length. The length, called a cubit, was originally defined as the distance between the elbow and the tip of the middle finger.

640 B.C.
Standard Units of Weight
Merchants in the Middle East and Mediterranean used units of weight to be sure that they received the correct amount of gold and silver in trade and to check the purity of the metal. A *talent* was about 25 kilograms, and a *mina* was about 500 grams. The Lydians minted the first true coins to have standard weight and value.





200 B.C.
Standard Measures
Shih Huang Ti, the first emperor of China, set standards for weight, length, and volume. He also improved travel conditions by setting standards for the widths of roads and for the distance between chariot wheels.

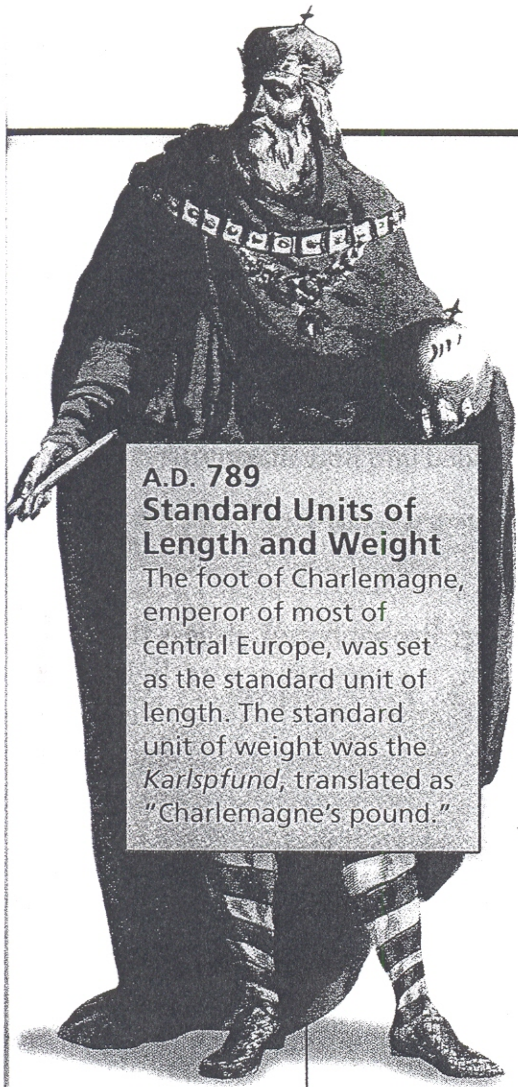
1500 B.C. | 1000 B.C. | 500 B.C. | A.D. 1

To measure objects smaller than a meter, scientists use units called the centimeter (cm) or the millimeter (mm). The prefix *centi-* means "one-hundredth," while the prefix *milli-* means one-thousandth. One meter, then, is equal to 100 centimeters or 1,000 millimeters. The length of a typical sheet of loose-leaf paper is 28 centimeters, which is equal to 280 millimeters.

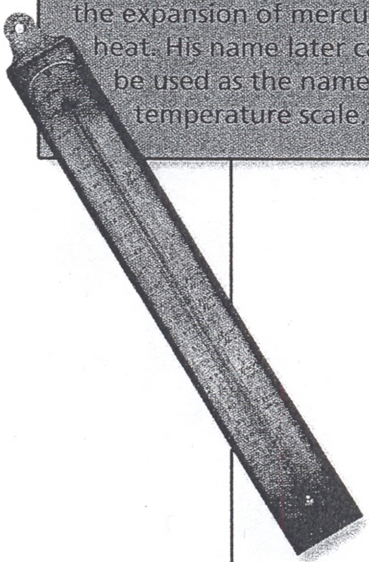
What unit would you use to measure a long distance, such as the distance between two cities? For such measurements, scientists use a unit known as the kilometer (km). The prefix *kilo-* means one thousand. There are 1,000 meters in a kilometer. If you were to draw a straight line between San Francisco and Boston, the line would measure about 4,300 kilometers.

Writing in Science

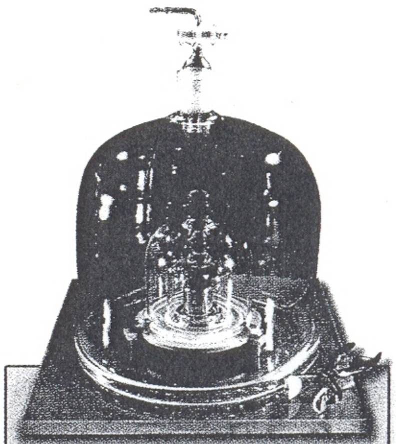
Research and Write While scientists rely on SI units, people use different measurement units for other purposes. Research the units used in sailing, horse breeding, diamond cutting, farming, or another activity that interests you. Write a few paragraphs about your findings.



A.D. 789
Standard Units of Length and Weight
The foot of Charlemagne, emperor of most of central Europe, was set as the standard unit of length. The standard unit of weight was the *Karlspfund*, translated as "Charlemagne's pound."



A.D. 1714
Thermometer
Gabriel Fahrenheit invented the thermometer, a temperature-measuring device that relies on the expansion of mercury with heat. His name later came to be used as the name for a temperature scale.



A.D. 1983
International Standards
The International Bureau of Weights and Measures in France defined a single set of standard units. Scientists throughout the world use these units in their work. The official kilogram measure, shown above, is kept in a vacuum chamber.

A.D. 500 | A.D. 1000 | A.D. 1500 | A.D. 2000

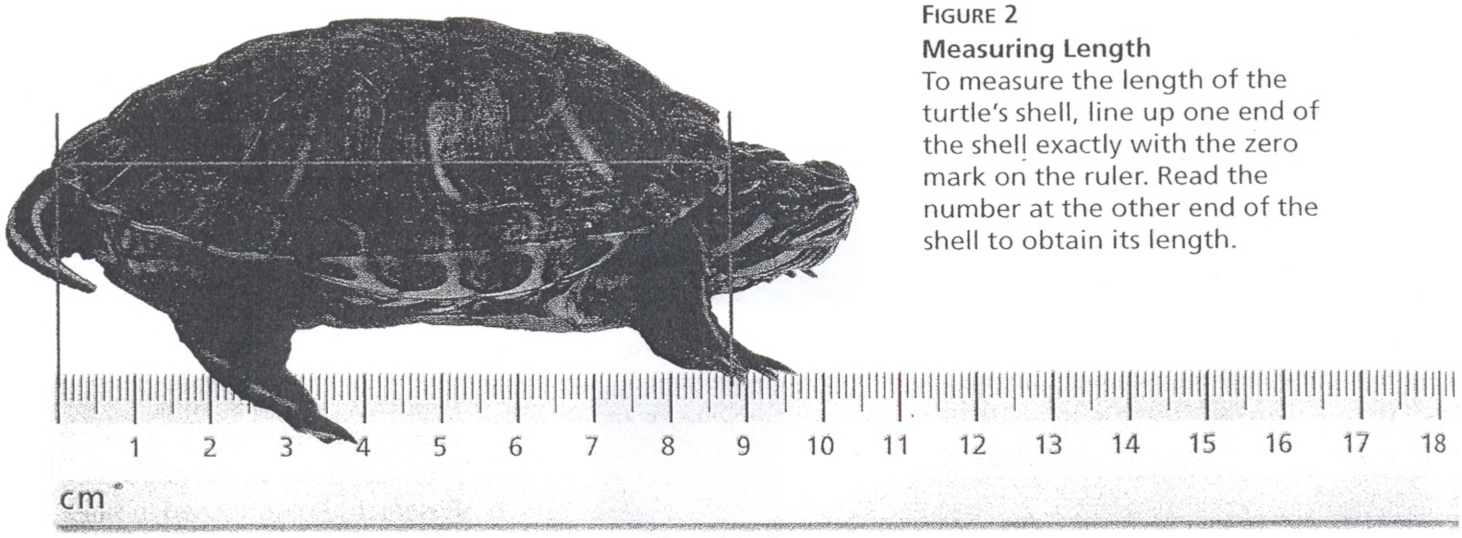


FIGURE 2
Measuring Length
To measure the length of the turtle's shell, line up one end of the shell exactly with the zero mark on the ruler. Read the number at the other end of the shell to obtain its length.

Measuring Length A very common tool used to measure length is the metric ruler. As you can see in Figure 2, a metric ruler is divided into centimeters. The centimeter markings are the longer lines numbered 1, 2, 3, and so on. Each centimeter is then divided into 10 millimeters, which are marked by the shorter lines.

To use a metric ruler, line one end of the object up exactly with the zero mark. Then read the number at the other end of the object. The shell of the turtle in Figure 2 is 8.8 centimeters, or 88 millimeters, long.

Reading Checkpoint **One centimeter is divided into how many millimeters?**

Mass

Can you lift a bicycle with one finger? Probably not, unless the bicycle's frame is made of titanium, a strong but very light metal. Most bike racers use titanium frames because the bike's low mass allows them to ride faster. **Mass** is a measure of the amount of matter an object contains.

Units of Mass **The basic unit of mass in the SI system is the kilogram (kg).** The kilogram is a useful unit when measuring the mass of objects such as bicycles, cars, or people. The mass of a wooden baseball bat is about 1 kilogram.

To measure the mass of smaller objects, you will use a unit known as the gram (g). As you can guess, there are 1,000 grams in a kilogram. A large paper clip has a mass of about 1 gram. Even smaller masses are measured in milligrams (mg). There are 1,000 milligrams in one gram.

Common Conversions for Mass		
1 kg	=	1,000 g
1 g	=	1,000 mg

Measuring Mass To find the mass of an object, you may use a balance like the one in Figure 3. This balance, known as a triple-beam balance, works by comparing the mass of the object you are measuring to a known mass. When you use a triple-beam balance, you first place the object on the pan. You then shift the riders on the beams until they balance the mass of the object. You can find step-by-step instructions for using a triple-beam balance in Appendix C.

The Difference Between Mass and Weight Mass is often confused with weight. But weight is not the same thing as mass. **Weight** is a measure of the force of gravity acting on an object. As you probably know, you can measure an object's weight using a scale. When you stand on a scale, gravity pulls you downward, compressing springs inside the scale. The more you weigh, the more the springs compress, and the higher the reading.

If, however, you were to weigh yourself on the moon, you would obtain a very different reading. Because the force of gravity is much weaker on the moon than on Earth, the springs inside the scale would compress much less. You would weigh less on the moon. But how would your mass compare? Because mass measures the amount of matter an object contains, it remains constant wherever an object may be. Your mass on the moon is the same as your mass on Earth. You can see why scientists prefer to use mass, rather than weight, when making measurements.

Reading Checkpoint **What is weight?**

Lab zone Skills Activity

Measuring

Use a balance to determine the mass of the following objects

- a CD
- a crumpled sheet of notebook paper
- this textbook

Compare your measurements to those of a classmate. How close are the two sets of measurements?

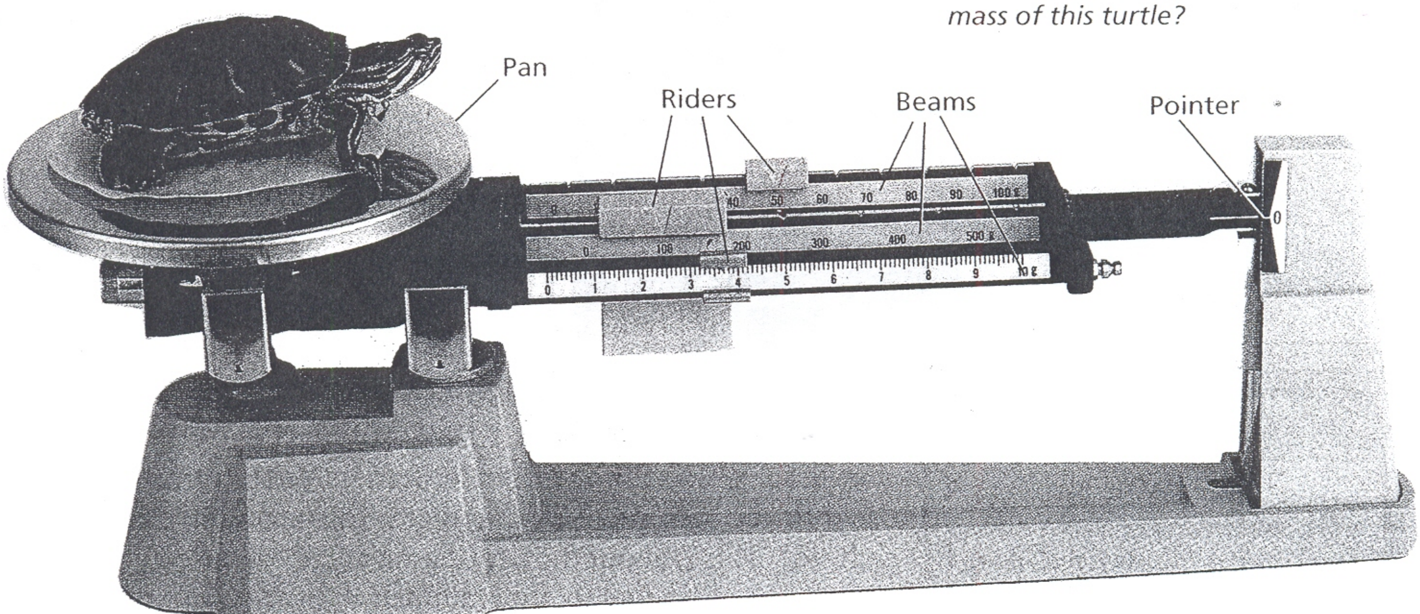


FIGURE 3
Measuring Mass
You can use a triple-beam balance to find the mass of small objects. To measure mass, place the object on the pan and shift the riders on each beam until the pointer stops at zero. **Observing** *What is the mass of this turtle?*

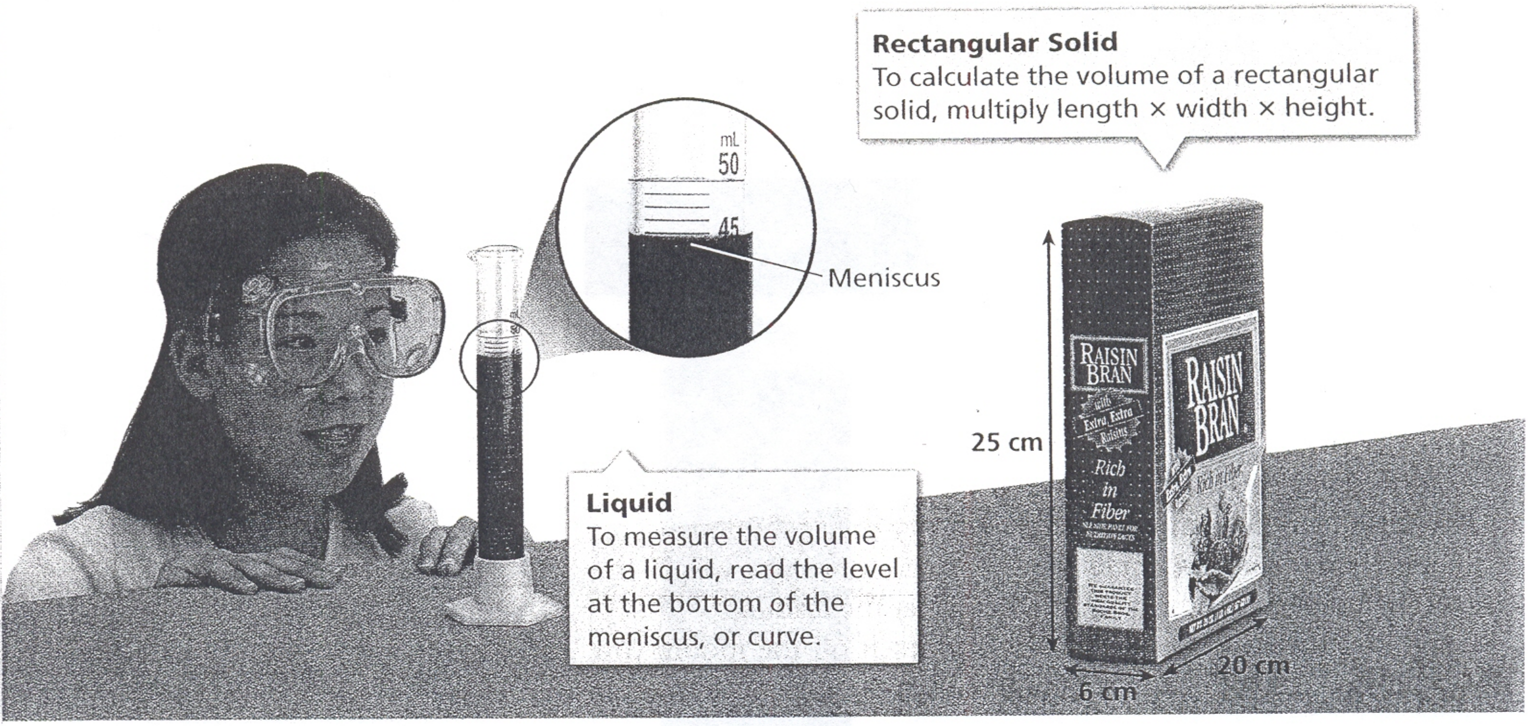


FIGURE 4
Measuring Volume
Volume is the amount of space an object takes up. Measuring the volume of liquids, rectangular solids, and irregular solids requires different methods.
Observing *What is the proper way to read a meniscus?*

Common Conversions for Volume		
1 L	=	1,000 mL
1 L	=	1,000 cm^3
1 mL	=	1 cm^3

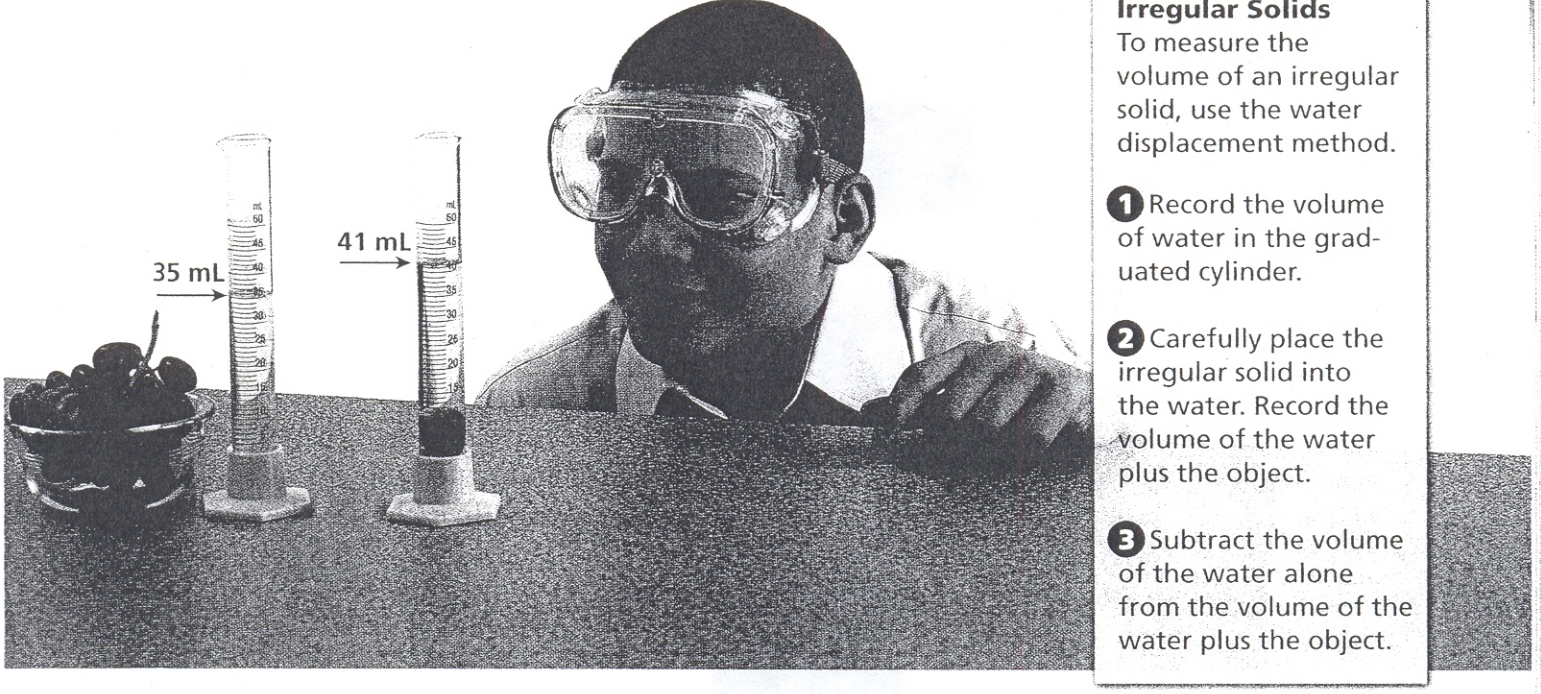
Volume

Do you drink milk or orange juice with breakfast? If so, how much do you have? You probably don't measure it out; you just pour it into a glass. You decide when to stop pouring by observing the amount of space it fills in the glass. **Volume** is the amount of space an object takes up.

Volume of Liquids To measure the volume of a liquid, scientists use a unit known as the liter (L). You have probably seen 1-liter and 2-liter bottles of beverages at the grocery store. You can measure smaller liquid volumes using milliliters (mL). There are 1,000 milliliters in a liter.

To measure the volume of a liquid, just pour it into a container with markings that show the volume. Scientists commonly use a graduated cylinder to measure liquid volumes. The graduated cylinder in Figure 4 is marked off in 1-milliliter segments. Notice that the top surface of the water in the graduated cylinder is curved. This curve is called the **meniscus.** To determine the volume of water, you should read the milliliter marking at the bottom of the curve.

Volume of Rectangular Solids How can you determine the volume of a solid object, such as a cereal box? The unit you would use is the cubic centimeter (cm^3). A cubic centimeter is equal to the volume of a cube that measures 1 centimeter on each side. This is about the size of a sugar cube. One cubic centimeter is exactly equal to one milliliter.



Irregular Solids
To measure the volume of an irregular solid, use the water displacement method.

1. Record the volume of water in the graduated cylinder.
2. Carefully place the irregular solid into the water. Record the volume of the water plus the object.
3. Subtract the volume of the water alone from the volume of the water plus the object.

For solids with larger volumes, scientists use the SI unit known as the cubic meter (m^3). A cubic meter is equal to the volume of a cube that measures 1 meter on each side.

You can calculate the volume of a regular solid using this formula:

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Height}$$

Suppose that a cereal box is 20 centimeters long, 6 centimeters wide, and 25 centimeters high. The volume of the box is

$$\text{Volume} = 20 \text{ cm} \times 6 \text{ cm} \times 25 \text{ cm} = 3{,}000 \text{ cm}^3$$

Notice that, when you calculate volume, in addition to multiplying the numbers ($20 \times 6 \times 25 = 3{,}000$), you also multiply the units ($\text{cm} \times \text{cm} \times \text{cm} = \text{cm}^3$). Therefore, you must be sure to use the same units for all measurements when calculating the volume of a regular solid.

Volume of Irregular Solids Suppose you wanted to measure the volume of a rock. Because of its irregular shape, you can't measure a rock's length, width, or height. How, then, could you find its volume? One method is to immerse the object in water, and measure how much the water level rises. This method is shown in Figure 4.

Reading Checkpoint What is a cubic meter?

Go Online
PHSchool.com

For: More on measurement
Visit: PHSchool.com
Web Code: cgd-6021

FIGURE 5
Comparing Densities
Although the bowling ball and beach ball have the same volume, one contains much more mass than the other. **Inferring** *Which item has the greater density?*

Density

As you can see in Figure 5, two objects of the same size can have very different masses. This is because different materials have different densities. **Density** is a measure of how much mass is contained in a given volume. To calculate the density of an object, divide its mass by its volume.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Units of Density **Because density is actually made up of two other measurements—mass and volume—an object's density is expressed as a combination of two units.** Two common units of density are grams per cubic centimeter (g/cm^3) and grams per milliliter (g/mL). In each case, the numerator is a measure of mass while the denominator is a measure of volume.

Math Sample Problem

Calculating Density

Suppose that a metal object has a mass of 57 g and a volume of 21 cm^3. Calculate its density.

1 Read and Understand
What information are you given?
Mass of metal object = 57 g
Volume of metal object = 21 cm^3

2 Plan and Solve
What quantity are you trying to calculate?
The density of the metal object = $\blacksquare$

What formula contains the given quantities and the unknown quantity?

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Perform the calculation.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{57\text{ g}}{21\text{ cm}^3} = 2.7\text{ g/cm}^3$$

3 Look Back and Check
Does your answer make sense?
The answer tells you that the metal object has a density of 2.7 g/cm^3. The answer makes sense because it is the same as the density of a known metal—aluminum.

Math Practice

1. What is the density of a wood block with a volume of 125 cm^3 and a mass of 57 g?
2. What is the density of a liquid with a mass of 45 g and a volume of 48 mL?

Densities of Common Substances The table in Figure 6 lists the densities of some common substances. The density of a substance is the same for all samples of that substance. For example, all samples of pure gold—no matter how large or small—have a density of 19.3 g/cm^3.

Once you know an object's density, you can determine whether or not the object will float in a given liquid. An object will float if it is less dense than the surrounding liquid. For example, the density of water is 1 g/cm^3. A piece of wood with a density of 0.8 g/cm^3 will float in water. A ring made of pure silver, which has a density of 10.5 g/cm^3, will sink.

Reading Checkpoint **Will an object with a density of 0.7 g/cm^3 float or sink in water?**

Densities of Some Common Substances	
Substance	Density (g/cm^3)
Air	0.001
Ice	0.9
Water	1.0
Aluminum	2.7
Gold	19.3

FIGURE 6
The density of a substance stays the same no matter how large or small a sample of the substance is. **Applying Concepts** *How could you use density to determine whether a bar of metal is pure gold?*

Time

The crowd cheers wildly as you near the finish line. You push your legs to run even faster in the final moments of the race. From the corner of your eye, you see your opponent catching up to you. At moments like this, just one second can mean the difference between winning and losing.

Units of Time **The second (s) is the SI unit used to measure time.** Your heart beats about once per second—when you are not running, that is! The second can easily be divided by multiples of 10, like the other SI units. For example, a millisecond (ms) is one-thousandth of a second. Longer periods of time are expressed in minutes or hours. There are 60 seconds in a minute, and 60 minutes in an hour.

Measuring Time Clocks and watches are used to measure time. Some clocks are more accurate than others. Some digital stopwatches, which are used to time races, can measure time accurately to one hundredth of a second.

Reading Checkpoint **How many milliseconds are in one second?**

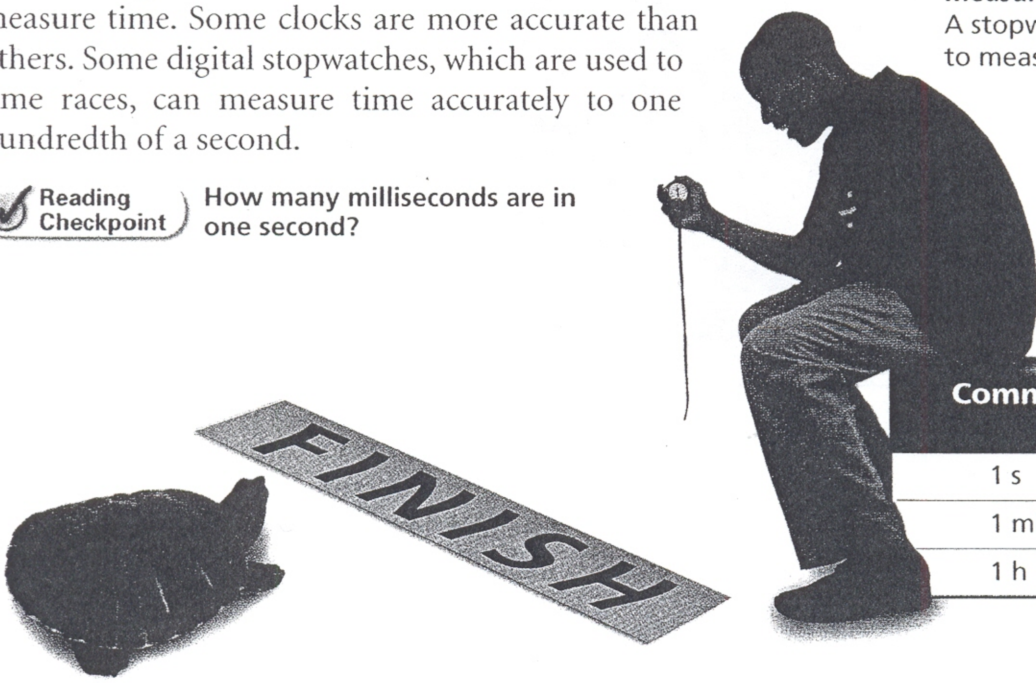


FIGURE 7
Measuring Time
A stopwatch can be used to measure time.

Common Conversions for Time		
1 s	=	1,000 ms
1 min	=	60 s
1 h	=	60 min

Temperature

As you head out the door each morning, one of the first things you might notice is the temperature. Is it cold out this morning? How high will the temperature rise?

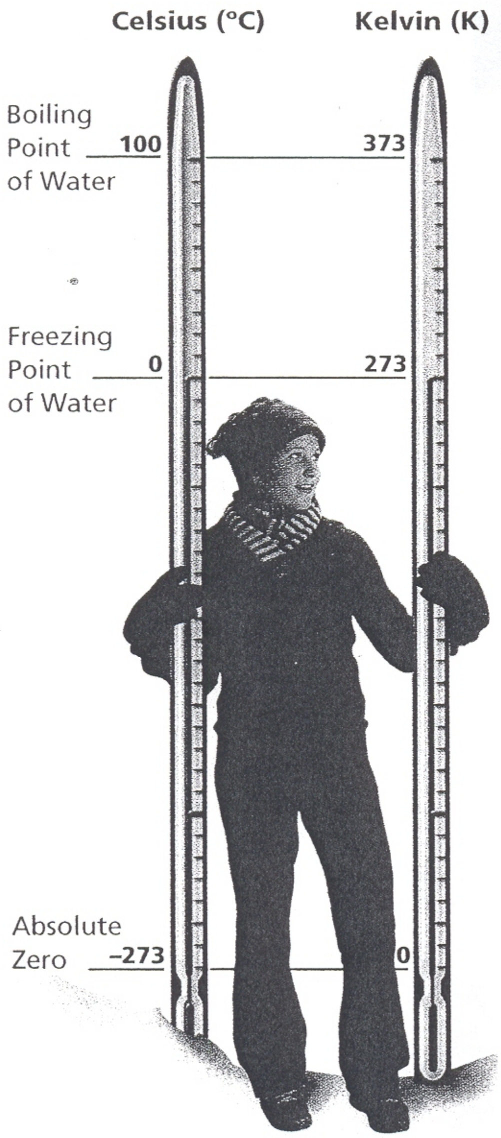


FIGURE 8
Measuring Temperature
Scientists use the Celsius and Kelvin scales to measure temperature. Units on both scales are the same size.
Observing *At what temperature on the Kelvin scale does water boil?*

Common Conversions for Temperature		
0°C	=	273 K
100°C	=	373 K

Units of Temperature Scientists commonly use the Celsius temperature scale. On the Celsius scale, water freezes at 0°C and boils at 100°C. There are exactly 100 degrees between the freezing point and boiling point of water. Normal human body temperature is about 37°C.

In addition to the Celsius scale, scientists sometimes use another temperature scale, called the Kelvin scale. In fact, the kelvin (K) is the official SI unit for temperature. Units on the Kelvin scale are the same size as those on the Celsius scale. Figure 8 compares these two temperature scales.

Zero on the Kelvin scale (0 K) is the temperature that scientists consider to be the coldest possible temperature. Nothing can get colder than this temperature, called absolute zero. Absolute zero is equal to –273°C on the Celsius scale. The Kelvin scale is useful because it does not have negative numbers to complicate calculations.

Measuring Temperature You can measure temperature using a thermometer. When you first place the thermometer in a substance, the liquid inside the thermometer will begin to move up or down. Wait until the level of the liquid stops changing. Then read the number next to the top of the liquid in the thermometer.

Reading Checkpoint **What is the official SI unit for temperature?**

Converting Between Units

Do you have a jar where you keep all your pennies? Suppose you counted your penny collection and discovered that you had 236 pennies. How many dollars does that equal? With only a little thought, you could probably answer, "$2.36."

Just like converting between dollars and cents, it is often necessary to convert from one unit of measurement to another. **To convert one measurement to another, you need to know the appropriate conversion factor. A conversion factor is an equation that shows how two units of measurement are related.** For conversion factors, refer to the conversion tables included throughout this section.

Suppose you walk 1.5 kilometers to a friend's house. How many meters have you walked? To convert 1.5 kilometers to meters, follow these steps:

❶ Begin by writing down the measurement you want to convert.

❷ Find a conversion factor that relates the two units you are converting.

❸ Write the conversion factor as a fraction. Make sure to place the units you are converting from in the denominator.

❹ Multiply the measurement you are converting from by the fraction. When you do this, the units in the measurement will cancel out with the units in the denominator of the fraction. Your answer will then be in the units you are converting to.

By converting between units, you now know that you walked 1,500 meters to your friend's house.

Reading Checkpoint What is a conversion factor?

❶ $1.5 \text{ km} = \underline{?} \text{ m}$

❷ $1 \text{ km} = 1{,}000 \text{ m}$

❸ $\dfrac{1{,}000 \text{ m}}{1 \text{ km}}$

❹ $1.5 \cancel{\text{km}} \times \dfrac{1{,}000 \text{ m}}{1 \cancel{\text{km}}} = 1{,}500 \text{ m}$

$1.5 \text{ km} = 1{,}500 \text{ m}$

FIGURE 9
Converting Between Units
Using the appropriate conversion factor, you can easily convert one unit of measurement to another. This example shows how to convert 1.5 kilometers to meters.

Section 1 Assessment

Target Reading Skill

Comparing and Contrasting Use the information in your table about the different types of measurement to answer Question 2.

Reviewing Key Concepts

1. a. **Identifying** What is the standard measurement system used by scientists around the world?
   b. **Predicting** Suppose that two scientists use different measurement systems in their work. What problems might arise if they shared their data?
2. a. **Listing** What SI unit would you use to measure the length of a baseball bat? What SI unit would you use to measure the mass of a baseball?
   b. **Estimating** Estimate the length of a baseball bat and mass of a baseball. Be sure to use the appropriate SI units in your predictions. How could you determine how close your estimates are?
   c. **Problem Solving** Outline a step-by-step method for determining the density of a baseball.
3. a. **Reviewing** What is a conversion factor?
   b. **Identifying** What conversion factor would you use to convert between liters and milliliters?
   c. **Calculating** Your cat's bowl holds 0.25 liters of liquid. How many milliliters of water can you pour into the bowl?

Math Practice

Two solid cubes have the same mass. They each have a mass of 50 g.

4. **Calculating Density** Cube A has a volume of 2 cm × 2 cm × 2 cm. What is its density?
5. **Calculating Density** Cube B has a volume of 4 cm × 4 cm × 4 cm. What is its density?